RECENT SKID RESISTANCE EVALUATIONS OF CONCRETE BLOCK PAVING IN NORTH AMERICA

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ABSTRACT

Factors influencing skid resistance are reviewed as well as static and dynamic methods for its measurement. A review of the literature on skid resistance on concrete block pavement is provided. Research results are given on skid resistance of concrete block paving in 1997 conducted by the Pennsylvania Transportation Institute, the center for skid resistance evaluation in the United States. Research for the Interlocking Concrete Pavement Institute (ICPI) use the test method described in ASTM E 274, Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire. This method is used by many state agencies to evaluate the skid resistance of highways. Results are compared to reference values for conventional asphalt highway pavements. A brief discussion is provided on the efforts by the Permanent International Road Congress (PIARC) to harmonize various texture and friction measurements through and International Friction Index.

1. INTRODUCTION

Skid resistance of tires on pavement are important to safety in traversing streets and airfields. While many variables influence skid resistance, concrete block pavements offer surface characteristics that provide resistance and added safety when compared to other pavement surfaces. This paper provides an overview of research on skid resistance on concrete block paving with concentration on recent studies in the United States.

2. DEFINING SKID RESISTANCE

Skid resistance is the resistance to motion between the pavement and vehicle tires. Pavement-tire friction is influenced by the following factors (1):

Pavement characteristics such as texture, roughness, and rutting

Pavement texture consists of microtexture and macrotexture. Macrotexture is defined as 0.5 mm or greater deviations in the surface (from a true planar surface) that affect tire-pavement interaction. A pavement with good macrotexture contributes to skid resistance of vehicles traveling over 40 kph. Concrete pavers with chamfers offer a unique macrotexture that can benefit skid resistance at these speeds. Specifically, the chamfers form small drainage channels on the pavement surface to help disperse water under moving tires.

Microtexture is defined by smaller deviations in the surface, those less than 0.5 mm. Microtexture is the primary influence on skid resistance of vehicle tires traveling less than 40 kph. Microtexture varies with the hardness of the aggregate in concrete pavers. Harder aggregates are less likely to

polish under concentrated braking or accelerating tires thus maintaining a high degree of variation in the texture of the surface.

In many cases, concrete pavers conforming to applicable American (ASTM) or Canadian (CSA) standards do not require special aggregates to maintain skid resistance equal to that of asphalt or portland cement concrete (PCC) pavement surfaces. Like other paving materials, selection of aggregates (hardness, sharpness) and surface texture can be controlled in the mix design and manufacturing process for concrete pavers.

Should the need arise for special aggregates with high skid-resistant properties, laboratory research on a range of aggregates has provided some criteria for selecting aggregates with high skid resistance (2)(3) for conventional pavements. These can apply to concrete pavers. The criteria include the following:

- Results of petrographic analysis that show hard minerals combined with some softer minerals.
- Angular and large mineral grains in the individual aggregate particles.
- Aggregates with a high range of hardness as measured by the Moh's scale.
- Sand-sized and total insoluble residue in carbonate aggregates when subjected to acid-solubility tests.
- Resistance to wear in jar mill abrasion tests, small, laboratory circular test tracks, and relating these results to laboratory skid tests on sample pavements.

Roughness is described as large deviations in pavement surface, most of which affect ride comfort and dynamics of the vehicle. A rough pavement can cause the wheels to bounce and this can reduce friction. Rutting in wheel paths also reduces friction, especially when they fill with water from rainfall.

Tire characteristics including tire type, tire tread, and inflation pressure

Tire design and rubber formulations are often a trade-off between wearing and frictional characteristics. Harder rubber tires wear longer but do not offer the same frictional performance as softer rubber. Deep-treaded tires offer better frictional characteristics because they disperse more water. This is especially important at high speeds where the time for dispersing water from under tires is very short. Excess or low tire inflation pressure also can decrease the skid resistance.

Vehicle operational characteristics such as speed, tire slip, axle load, and the type of vehicle

Speed of the vehicle is one of the dominant factors in skid resistance. As speed increases, the amount of time to disperse water decreases and water on the pavement has a lubricating effect. When the brakes are applied, the velocity of tires decrease. If a tire's velocity decreases at a rate higher than the vehicle's velocity, the tires will slip on the pavement surface. When the brakes lock, the slipping becomes skidding. Anti-lock brake systems (ABS) are designed to balance the speed of the tires with that of the vehicle during braking, thereby preventing skidding and reducing slipping.

Tire-pavement friction generally decreases as axle load increases and trucks generally have a lower coefficient of friction than passenger cars. This is due to differences in tire compounds and hardness, and the higher temperatures at which truck tires operate.

Environmental factors involving wetness, ice and snow, contamination, and temperature

Engineers and road safety officials are most interested in the skid performance of pavement when it is wet since there is a dramatic difference between wet and dry skid characteristics. A pavement does not have to be completely flooded to realize a decrease in skid resistance. A film of water as thin as 0.002 in. (0.05 mm) can substantially decrease skid resistance. Ice, snow, and contamination (mud, oil, gravel, etc.) are all obvious contributors to the loss of skid resistance. Skid resistance decreases as ambient air and tire temperatures rise.

When considering road safety, pavement skid resistance is one of several factors, all of which may contribute to skid-related accidents, near misses, and ultimately characterize a pavement as safe or unsafe. Others influences on pavement skid resistance include:

Traffic characteristics such as average daily traffic, posted speed, and the percent of trucks in the traffic mix; curves and slopes in the road; and driving difficulty such as the number of turning lanes, access points, traffic signals, and surrounding land use.

Skid resistance is one of many factors influencing agency decisions on when to resurface or reconstruct a road. The age, traffic, a rough ride due to settlement and rutting, and citizen complaints are some other factors. Each agency has its own decision criteria for pavement maintenance and rehabilitation.

Figure 1 summarizes the relationship between pavement surface defined by wavelength and various characteristics (4) including texture and roughness.

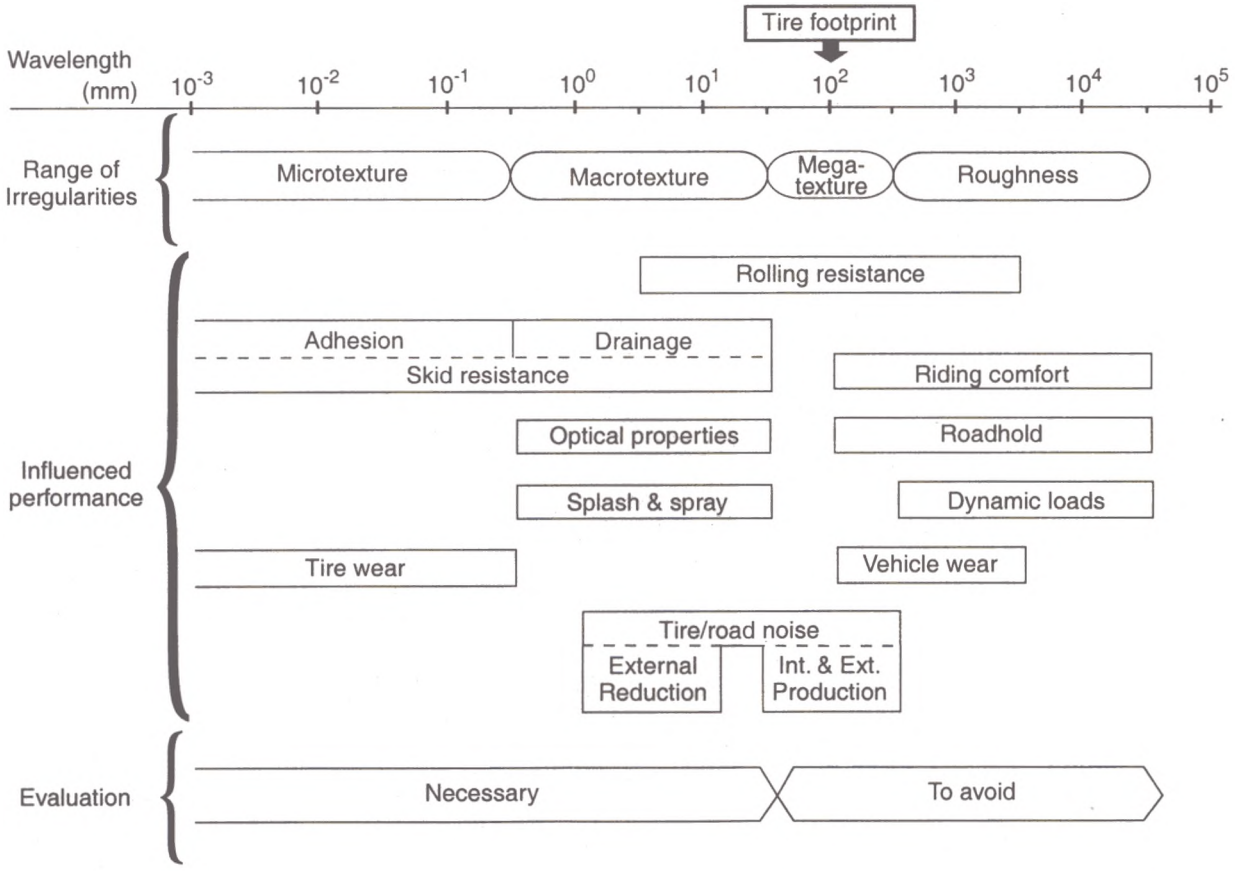

Figure 1. The role of pavement surface wavelength on various performance characteristics including skid resistance (4).

3. MEASURING PAVEMENT SKID RESISTANCE

There are two approaches to measuring skid resistance; static and dynamic. Static measuring devices measure resistance while moving across a small portion of the pavement. They do not involve the use of a tire. Dynamic devices make measurements with a tire while moving at a constant velocity across the pavement surface. A common device used for static measurement is the portable British Pendulum Tester. See Figure 2. This test method is described in ASTM E 303, Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester (5). This device is used for laboratory or on-site testing of skid resistance on surfaces. It consists of a small rubber shoe at the end of spring-loaded pendulum. The tester measures frictional resistance between the rubber shoe and the point of contact with the pavement. The contact area of the shoe against the test surface is about 19 cm^2, so measurements are influenced only by microtexture of the surface.

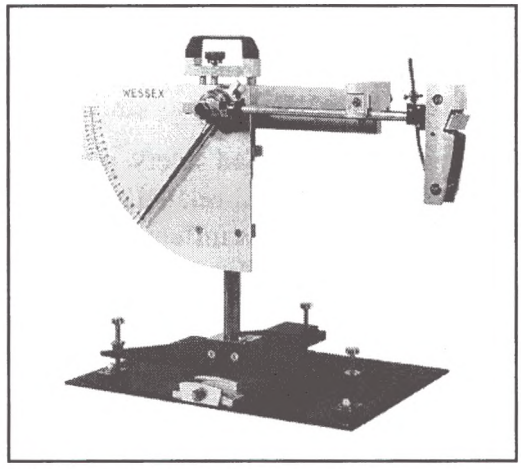

Figure 2. A British Pendulum Tester.

To perform a test, the test surface is wetted, the pendulum is pulled back, and the shoe rubs across the surface. Friction resistance is read on a scale on the machine as the British Pendulum Number or BPN. A BPN rating between 45 and 55 indicates a satisfactory surface in only favorable weather and vehicle conditions. A rating of 55 or greater indicates a generally acceptable skid resistance in all but the most severe weather conditions. A 65 and above rating indicates a good to excellent skid resistance in all conditions.

The BPN correlates with the performance of a vehicle braking with locked wheels on a wet pavement stopping from 50 kph. The tester is not designed to give ratings above 50 kph and results do not readily correlate to results from full-scale dynamic tests using a tire and trailer. The BPN test generally gives higher skid resistance ratings than dynamic tire and trailer tests.

Most dynamic skid resistance measurement methods assess the interaction between a pavement and a locked, non-rotating tire. These test methods employ a standard-sized tire towed in a wheeled device behind a vehicle. A standard amount of water is applied ahead of the tire while moving, the tire is locked while the vehicle maintains a constant speed and the resistance between the tire and the wet pavement is measured. Some dynamic skid testing devices include the Stradograph, the Sideways Force Coefficient Routine Investigation Machine (SCRIM)(6), and the Mu Meter (7).



Figure 3. ASTM E 274 Test Equipment consists of a truck and trailer assembly. A tire within the trailer is towed a given speed, locked, and skidded across water dispensed on the pavement in front of it.

In the North America, 40 state and provincial agencies use the test pro-

cedure described in ASTM E 274, Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire (8). Figure 3 illustrates the equipment. This test uses a standard test tire towed in a device behind a vehicle. A standard amount of water is applied ahead of the tire while moving, the tire is locked while the vehicle maintains a constant speed, usually 65 kph (40 mph), and the resistance between the tire and the wet pavement is measured. The force required to slide the tire is divided by the wheel load and multiplied by 100. The results are expressed as a skid number (SN) or friction number (FN).

Skid resistance measurements on asphalt pavements will vary with the time of year and weather. Since much skid data has been collected over the years for asphalt pavement, normalization procedures are used to eliminate influences of the season and weather. Weather and seasonal influences on PCC pavements produce less predictable results in skid testing. Therefore, no normalization procedures yet exist for PCC pavements.

4. LITERATURE REVIEW OF SKID RESISTANCE VALUES FOR CONCRETE BLOCK PAVEMENTS

A review of the literature on skid resistance of concrete pavers shows their skid resistance to be equal or better than asphalt. Most indicate that, subject to the proper mix design and manufacturing controls, concrete pavers can maintain good skid resistance values throughout the life of the pavement. Studies of static skid resistance by different researchers in various countries used the British Pendulum Tester to assess new and trafficked concrete pavers. A summary of test results follows:

Shackel (9) measured a bus route in Durban, South Africa after 17 years of traffic. BPN values averaged 61 with a standard deviation of 4.3. Clifford (10) conducted numerous tests at various locations in South Africa for the National Institute of Road Research. These tests included the locations and results listed in Table 1. Mavin (11)(12) measured BPNs in Melbourne, Australia, at 3 parking lots and on a quarry access road that received high truck traffic. BPNs on the new parking lots averaged 81 and declined to 53 with over three years of use. While BPNs for new concrete pavers dropped after use in the parking lots, the values did not fall below accepted standards. The 80kN Equivalent Single Axle (ESA) loads on the quarry road ranged from 0 to 150,000 over three years and BPNs increased from 45 initially to 62-65 at 75,000 to 150,000 ESAs.

Table 1—BPN Results by Clifford (12)

Location	BPN Range
1-year old city vehicle maintenance yard	48-61
8-year old residential pavement	54-59
20-year old residential pavements	41-55
5-year old access road to wind tunnel test facility	48-72
3-year old loading and servicing area next to government buildings	52-57
3 to 8-year old main and secondary roads at botanical gardens	45-85

Muira et al. (13) compared the performance of concrete pavers to asphalt put into service at the same time in a lightly trafficked street in Japan. After 12 months of service, BPNs for both the concrete pavers and the asphalt were 56 to 59. Sharp and Armstrong (14) showed that concrete pavers at a full-scale test track in Australia had an initial BPN of 70 and progressively decreased after installation and reached a minimum value of 57 after 460 ESAs.

Garrett and Walsh (15) tested an experimental access road leading to an industrial park and freight facility near Maidstone, England. After one year of testing pavers made by eight different manufacturers, results showed BPNs between 44 and 56. These values were considered

above those for county roads with similar traffic and risk levels.

Lesko (16) performed tests on 7 different areas of concrete pavers in a climbing lane with a 5% slope on a highway in Denmark. Initial BPNs ranged between 65 and 70 with values measured two years later between 49 and 60. Domenichini et al. (17) recorded BPNs on an 11-year old, 830 ft (253 m) long street with a 8% to 10% slope in the center of Recoara Terme, a small town in northern Italy. The average daily traffic was 1,230 vehicles in both directions with approximately 4% commercial trucks and buses Test results indicated BPNs of 49 on concrete pavers located in the wheel tracks and 69 outside the trafficked areas. The study noted that European standards for concrete block pavers recommends a minimum surface BPN of 45.

The first dynamic testing on concrete pavers was by Lesko (16) at 20, 60, and 80 kph using a Stradograph, a towed, treadless tire pitched at an oblique angle and locked while riding on wet pavement. Test results on 7 different (wet) concrete paver road sections over two years at these speeds showed values did not fall below 0.40 which is considered a satisfactory value for skid resistance.

The SCRIM device was used by Clifford (10) on concrete pavers at three of the sites as part of the aforementioned study that involved a British Pendulum Tester. SCRIM tests are typically at 50 kph or 80 kph using a treadless tire mounted on a vehicle at 20 degrees to the line of travel. The vehicle applies water in front of the loaded test wheel and the side force friction on the tire is measured. Tests by Clifford with the SCRIM device were conducted at 50 kph. In South Africa, the SCRIM target value for collector roads is 0.45; for arterial roads, 0.50; and for thoroughfares, 0.55. Results in Table 2 show a range from 0.25 to 0.85 with averages between 0.71 and 0.35.

Table 2—SCRIM Tests by Clifford (12)

Location	Average*	Range
1-year old city vehicle maintenance yard	63-71	25-85
5-year old Access road to wind tunnel test facility	62-77	45-85
3 to 8-year old main and secondary roads at botanical gardens	68-72	35-85

*Averages of measurements taken at several locations within the site

5. TESTS ON CONCRETE BLOCK PAVEMENT IN THE UNITED STATES BY THE PENNSYLVANIA TRANSPORTION INSTITUTE

The Interlocking Concrete Pavement Institute (ICPI) engaged The Pennsylvania Transportation Institute (PTI) to conduct skid measurements on two sections of new concrete block pavement (18). Two sections each measuring 0.6 m wide by 45 m long were laid in a 90 degree herringbone pattern. One was designated test section A and the other B since the concrete block pavers in A were supplied by one manufacturer and the units in section B were supplied by another manufacturer. See Figures 4 and 5.

60 mm thick rectangular units were compacted into a 25 mm thick sand bedding course. Joint sand was spread and compacted into the joints between the units. Excess sand was swept from the surface. The pavers and sand rested on an existing concrete base. Typically, 80 mm thick paving units are recommended in street applications. However, the depth of the existing concrete base allowed sufficient space for a layer of bedding sand and 60 mm thick units. The concrete units did not have a "face-mix" type surface of concentrated sand and cement.

Five skid resistance measurements were performed at three speeds; 40, 65, and 80 kph using the test method described in ASTM E 274. The test used a standard grooved test tire described in



Figure 4. The test track section and concrete paver surface at The Pennsylvania Transportation Institute test facility.

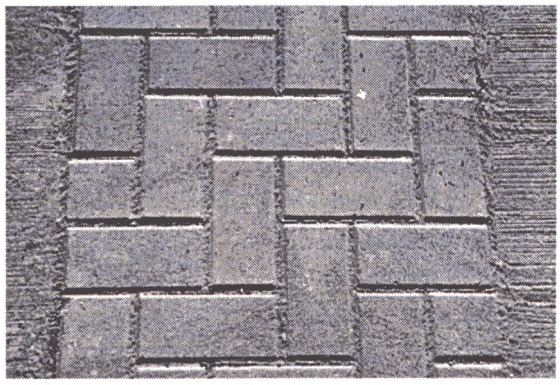

Figure 5. A close-up of the concrete paver surface at the PT1 test track.

ASTM E 501, Standard Specification for Standard Tire for Pavement Skid Resistance Tests (19). Tests were conducted in October 1997. The average results from the two sections are shown in Table 3. These are expressed a s Skid Numbers (SN).

Table 3—Average SN Values for Interlocking Concrete Pavement Sections (15)

Test Section	Speed kph	SN	Standard Deviation
A	40	51.9	0.5
A	65	46.5	1.1
A	80	40.0	1.5
B	40	57.2	1.1
B	65	49.6	3.0
B	80	43.1	0.5

6. SKID RESISTANCE REQUIREMENTS

Some states and provinces in North America have minimum skid resistance requirements in construction specifications for new pavements. These help ensure that the new pavement meets certain texture requirements before opening them to traffic. These requirements will vary based on the type of highway pavement, available materials and construction methods.

For testing in-service pavements, some consistency exists among highway agencies on test methods. Many use the ASTM E 274 test method; other states and provinces use the Mu Meter, or have developed their own tire and trailer equipment to derive a skid coefficient or f value. In most cases, the results from these test methods can be correlated to results using the ASTM E 274 test method.

Since test methods and traffic speeds vary over a wide range of conditions, no universal, minimum standard for skid resistance has been established. Typically, pavement engineers utilize the skid number measured using test method ASTM E 274 at 65 kph (40 mph) (i.e., SN40) as a reference value. Some researchers have attempted to define minimum skid requirements at certain speeds, on types of roads, and in particular regions. These can be used as overall guidelines rather than strict requirements when comparing skid resistance of conventional surfaces to concrete block pavements.

One study for roads in Virginia, USA, (20) suggested a minimum SN40 of 30 for Interstate and other divided highways, and a minimum SN40 of 40 for two-lane highways. Another study by the National Cooperative Highway Research Project (NCHRP) in 1967 (21) recommended minimum skid numbers for main rural highways. Table 4 shows the minimum skid numbers at

various traffic speeds, and those measured at 65 kph on roads with various traffic speeds. The test results on new concrete block pavement test at PTI indicate skid values well above those regarded by engineers as the minimum, and by the studies in references 20 an 21.

Table 4—Recommended Minimum Skid Number for Main Rural Highways (23)

Traffic Speed kph	SN Measured at traffic speed	SN measured at 65 kph
50	36	31
65	33	33
80	32	37
95	31	41
110	31	46

6. REDUCING TRAFFIC ACCIDENTS WITH CONCRETE BLOCK PAVEMENT

An important study in Japan demonstrates the ability of concrete block pavements to reduce accidents and increase safety at intersections (22). Accidents were monitored over 12 months and vehicle braking distances were measured with a high-speed video camera at an asphalt-paved intersection in Ichihara City. Daily traffic volumes on each street from 7:00 a.m. to 7:00 p.m. ranged between 3,479 and 7,119 vehicles.

After 6 months of monitoring traffic volume and accidents, the asphalt within and on the approaches to the intersection was removed and replaced with concrete pavers. The change in pavement surface reduced the number of accidents by 9 from December to May compared accidents counted in the previous June to November period.

Table 5—Stopping distance in meters on asphalt and concrete pavers (24)

	20 kph		40 kph		60 kph	
	Dry	Wet	Dry	Wet	Dry	Wet
Asphalt	1.70	3.20	5.85	9.60	14.2	26.7
Concrete pavers	1.68	2.50	5.23	8.15	13.6	21.3

The concrete pavers also reduced braking distances. A light-duty van was tested with three drivers on wet and dry conditions stopping from 20, 40, and 60 kph. Stopping distances were shorter on the concrete pavers and the greatest improvement was a reduction of 5 m at 60 kph as shown in Table 5. The contribution of the chamfers in the surface of the concrete pavers towards dispersing water may explain the reduction in stopping distances at this speed.

7. SKID RESISTANCE OF AIRCRAFT PAVEMENTS

Since 1983, over 1 million m^2 of concrete block pavements have been used in airfield applications. Tests conducted by airports and the U.S. National Aeronautics and Space Administration (NASA) demonstrate the skid resistant properties of concrete pavers. A

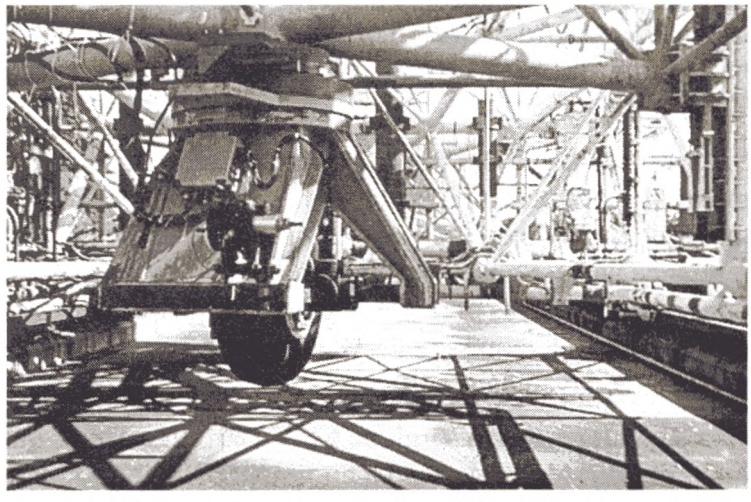

Figure 6. Test equipment for evaluation of the friction properties of concrete pavers at NASAs Aircraft Dynamics Landing Facility (ADLF) in Langley, Virginia.

NASA study (23) tested concrete block pavement at 5 knots and 100 knots/hour speed (1 knot/hour = 1.852 kph) at the Aircraft Landing Dynamics Facility in Langley, Virginia. The tests utilized a tire and 123 kN loads and 1.17 MPa pressure typical to a Boeing 737 or DC-9 aircraft. Figure 6 illustrates the test equipment and Figure 7 illustrates the test surfaces.

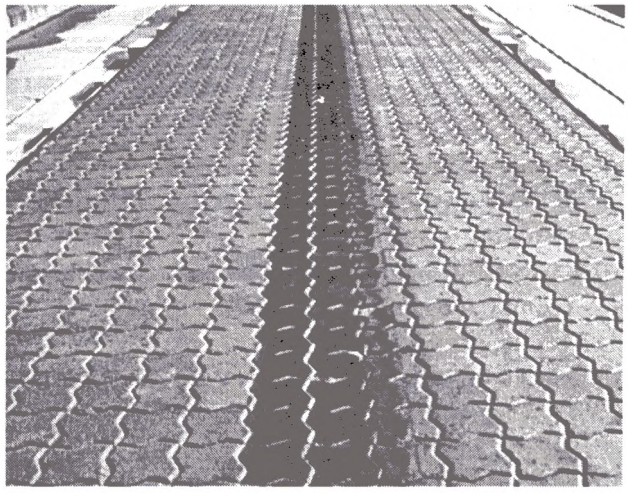

Figure 7. Test surface at the NASA ADLF facility.

The test results demonstrated substantially higher side force friction values for concrete pavers under wet conditions than plain portland cement concrete surfaces. The report indicated that for aircraft ground steering maneuvers under wet conditions, the paver blocks would provide better friction than the conventional smooth concrete surface (23).

Other skid resistance tests include that by Dallas/Fort Worth International Airport where a Saab skid tester was used to evaluate new concrete block pavements in 1990. The values derived from the test were 0.63 to 0.69 with 0.65 being the average value, all considered very good for a new airfield pavement (24).

8. HARMONIZATION OF SKID RESISTANCE TESTING

The Permanent International Road Congress (PIARC) is working to harmonize texture and friction measurements. The intended outcome is an International Friction Index that includes a friction number and a speed number. Therefore, all studies around the world with various test equipment will be correlated to this index. See internet: <http://www.aipcr.lcpc.fr/cgq/co1-gene.htm>.

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